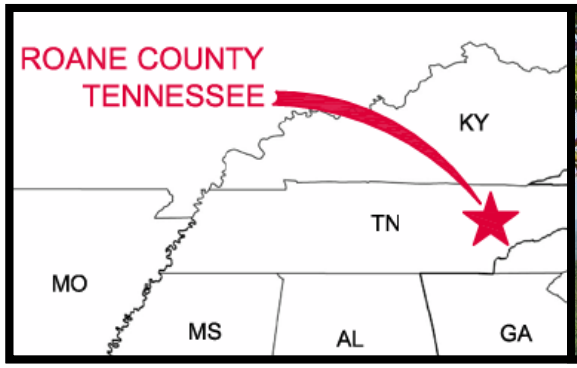
Development of Remedial Goals for Coal-Ash Associated Arsenic and Selenium in Support of Long-Term Site Monitoring

global expertise
applied locally

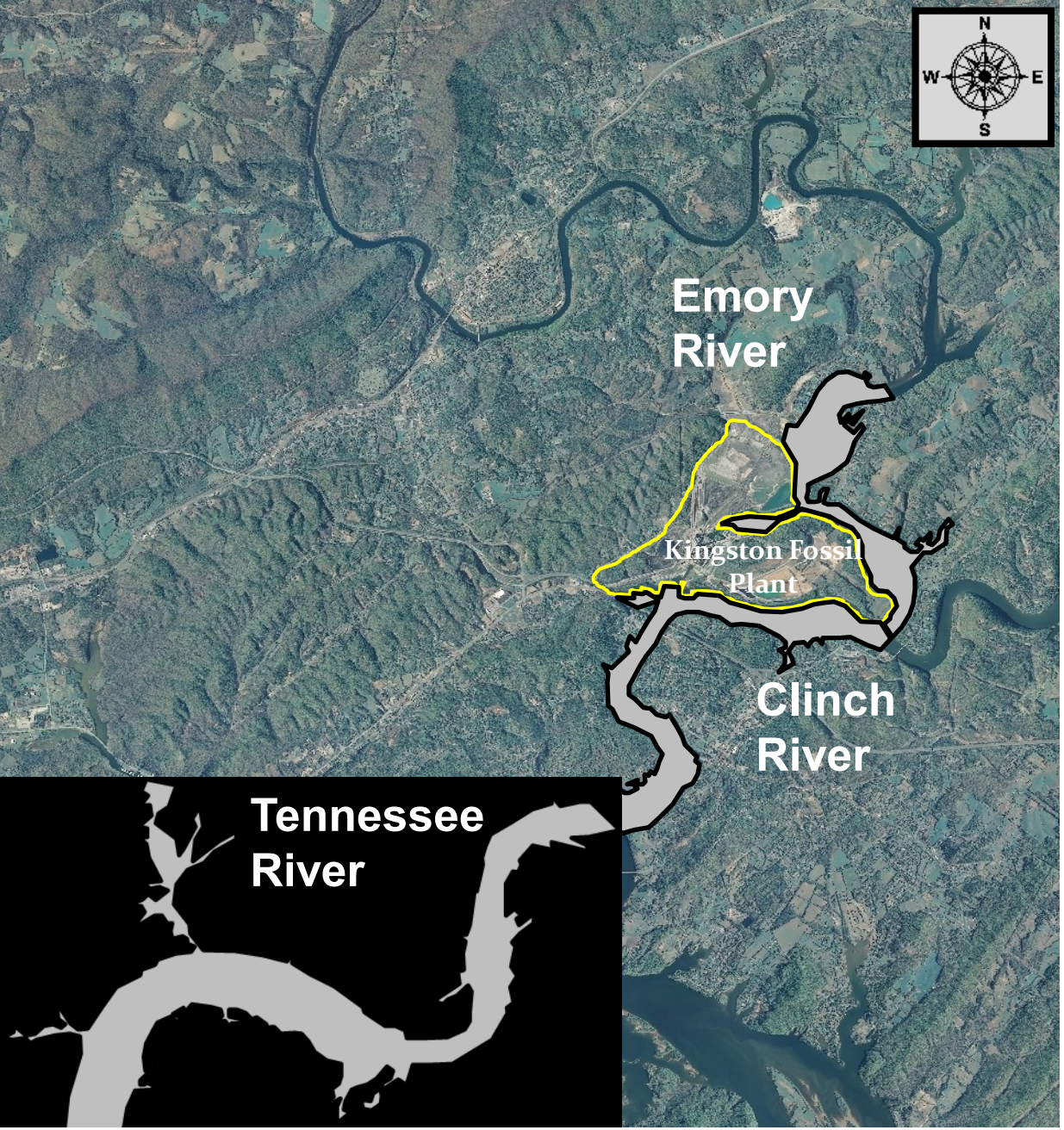
Amber Stojak
D. Ludwig; D. Jones; C. Meyer; T. Schlekat, S. Walls (ARCADIS)
N. Carriker; R. Sherrard (TVA)

Introduction



Ash is a by-product of coal-fired power plants

- Primarily comprised of aluminosilicate spheres
- Various metals occur naturally in the coal



Ash Migration

- Ash initially traveled upriver to Emory River mile (ERM) 5.75
- Ash was transported into the Clinch River
- Subsequent high flow events transported it downriver into the Tennessee River

CERCLA Strategy

Image: EPA SETAC 2010.

Time Critical Removal:

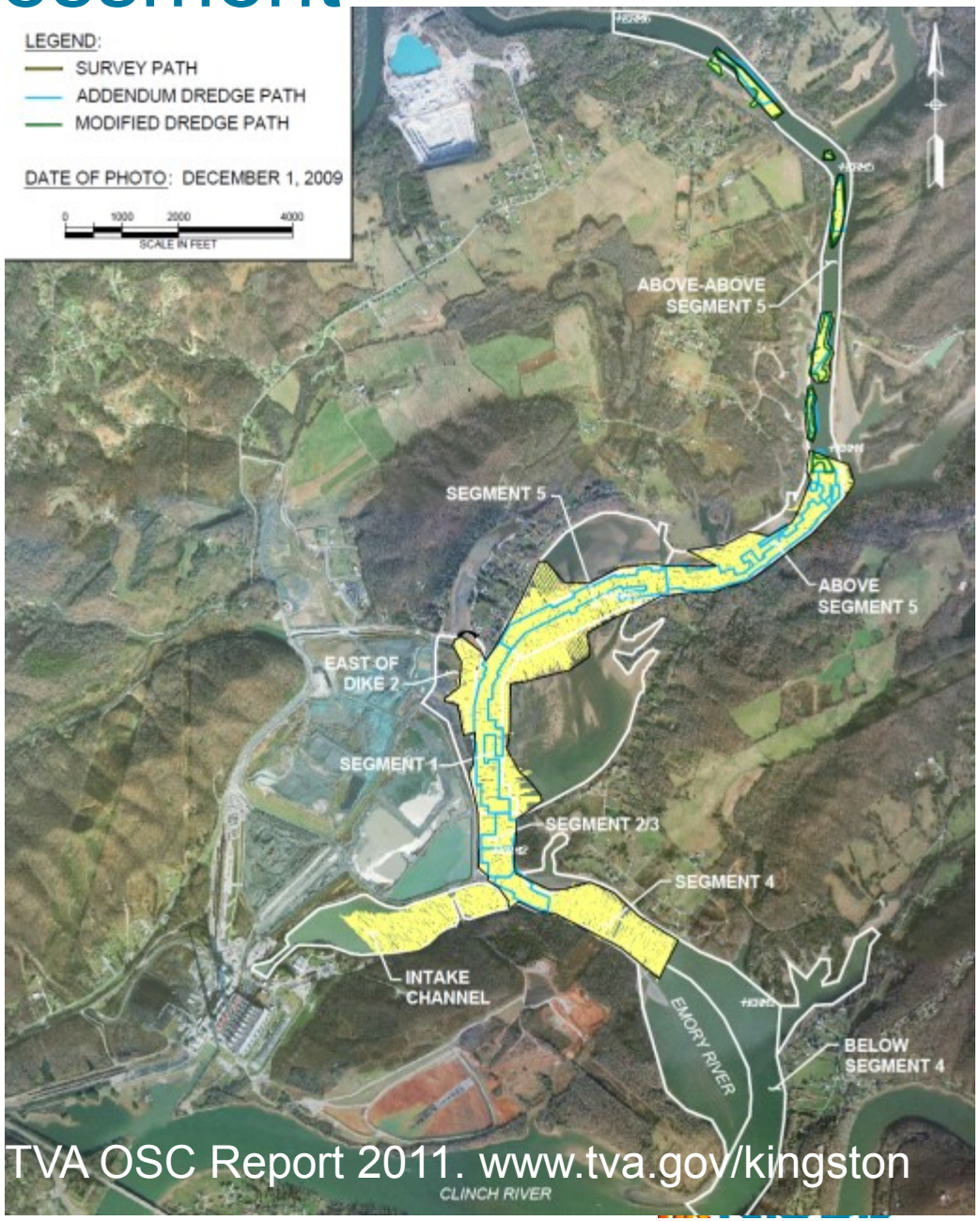
- Hydraulic and mechanical dredging
- Emory River reopened May 2010

Non-time Critical Removal:

- Embayments/Dredge Cell
  - Remove ash from embayments
  - Construct containment system
- River system residual ash study:
  - HHRA
  - BERA
  - EE/CA and Remedial Goals

Ecological Risk Assessment

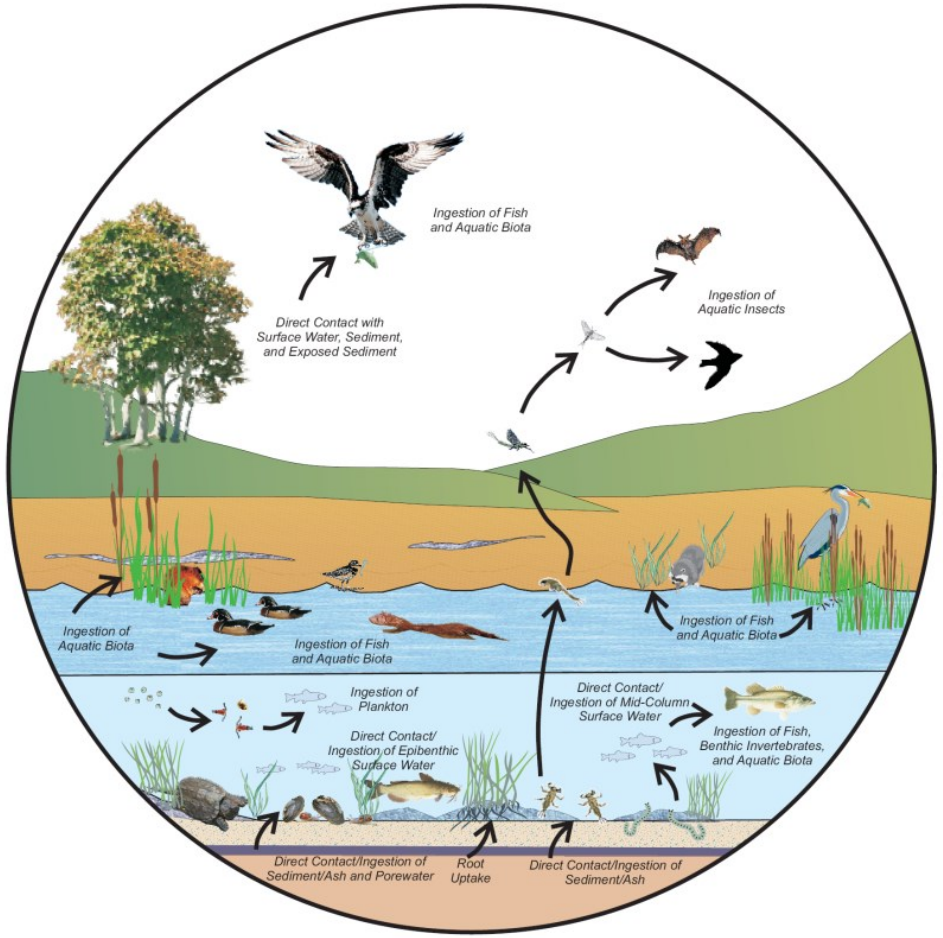
- The Baseline Ecological Risk Assessment (BERA) assessed potential effects of the ash release on ecological receptors in the river system
- Evaluated effects of post-dredging conditions
- Downstream of ERM 1.8 was not dredged due to legacy cesium-137



TVA OSC Report 2011. www.tva.gov/kingston

Ecological Receptors

- Aquatic plants
- Pelagic fish
- Benthic fish
- Benthic invertebrates
- Aquatic- or riparian-feeding birds
  - Herbivores (wood duck)
  - Omnivores (mallard; killdeer)
  - Piscivores (osprey; great blue heron)
- Aquatic- or riparian-feeding mammals
  - Herbivores (muskrat)
  - Omnivores (raccoon)
  - Piscivores (mink)
- Aerial-feeding insectivores
  - Birds (tree swallow)
  - Mammals (gray bat)
- Aquatic- or riparian-feeding reptiles
- Aquatic- or riparian-feeding amphibians



Receptors	Potential Risk	Confidence in Risk Determination	Risk Management Recommended?	COECs
Fish	⊘	Moderate		
Benthic Invertebrates	◒ (ER) ○ (CR)	High	✓	As, Se, Ash
Aquatic Vegetation	○	Moderate		
Birds				
Piscivore - Heron	⊘	Moderate		
Piscivore - Osprey	⊘	Moderate		
Insectivore - Killdeer	○	Low	✓	As, Se
Omnivore - Mallard	○	Moderate		
Herbivore - Wood Duck	⊘	Moderate		
Aerial Insectivore - Tree Swallow	○	Moderate	✓	Se
Mammals				
Carnivore - Mink	○	Low		
Omnivore - Raccoon	○	Low		
Herbivore- Muskrat	⊘	Low		
Aerial Insectivore - Gray Bat	○	Low		
Amphibians				
American Toad, Spring Peeper and Chorus Frogs	⊘	Moderate		
Reptiles				
Musk, Snapping, and Softshell Turtles	⊘	Moderate		

⊘ = risks are negligible; ○ = risks are low; ◒ = risks are moderate; ● = risks are high; ✓ = risk management is recommended.

Remedial Goals Based on BERA Results

- Remedial goals (RGs) for sediment provide goals for the selected remedy (monitored natural attenuation)
- Set targets for meeting primary ecological endpoints
- RGs developed for ash, arsenic, and selenium
- Set targets based on results from:
  - Sediment toxicity tests
  - Dietary exposure models

Benthic Invertebrates

- Community Surveys
- Sediment Toxicity Tests
- Invertebrate Tissue
- Abiotic Media

Remedial Goals

TVA Tiered Sediment Toxicity Test Design

"Screening"

10-day Survival & Growth

(No Dilutions)

10-day Survival & Growth

(No Dilutions)

Total Samples = 16 + References

28-day Survival & Growth Test

(Dilution series with 4 controls)

Partial Life Cycle Survival & Emergence Test

(Dilution series with 4 controls)

Total Samples = 8 + References

[Tests Conducted in Accordance with EPA 2000 and ASTM 2010]

Sediment from 18 areas in Emory and Clinch Rivers

- **Screening** sites selected based on: ash content; samples in each reach; grain sizes
- **Long-Term** sites selected based on: Sites with greatest observed effects in screening

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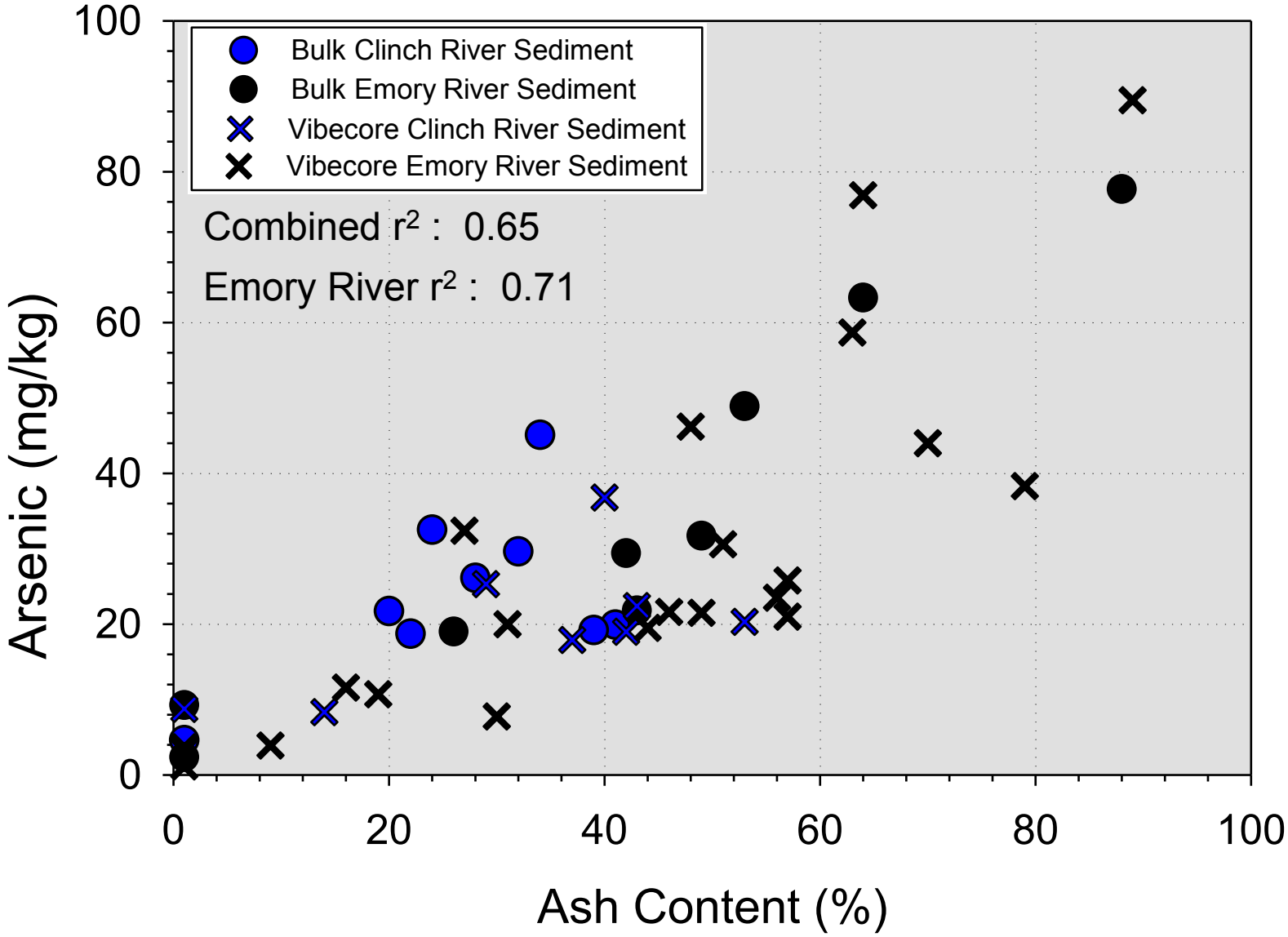
Arsenic Correlated with Ash



Statistical Correlations - Pearson's

Analytes	Ash	*C. dilutus* IC_{25} Survival	*C. dilutus* IC_{25} Emergence	*H. azteca* IC_{25} Survival	*H. azteca* IC_{25} Biomass
Ash	1.00	-0.81	-0.77	-0.95	-0.76
Arsenic	0.89	-0.83	-0.79	-0.91	-0.78
Arsenate	0.81	-0.80	-0.77	-0.99	-0.74
Arsenite	0.76	-0.71	-0.67	-0.56	**-0.65**
Selenium	0.75	-0.80	-0.78	-0.67	-0.72
Selenate	-0.43	0.85	0.86	0.60	0.52
Selenite	0.72	-0.72	-0.68	-0.94	-0.82

- % Ash correlated strongest with arsenic and selenium
- Arsenic correlated strongest with the toxicity test endpoints
- Other correlations (to a lesser extent) to % ash and toxicity tests:
  - Barium, beryllium, boron, chromium, strontium, and vanadium

Remedial Goals – Sediment Toxicity Tests

- Total arsenic and selenium concentrations associated with the IC_{25} test endpoint were calculated

	Chironomid	Hyalella
Average Arsenic IC_{25}	29 mg/kg	41 mg/kg
Arsenic PEC	33 mg/kg	
Average Selenium IC_{25}	2.8 mg/kg	3.2 mg/kg
Selenium PEC	No known consensus-based PEC	
Ash Content IC_{25}	50% Ash	

Tree Swallows and Killdeer

- Tree swallows:
  - Egg collections
  - Nestling tissues
  - Population surveys
- Killdeer and tree swallows:
  - Dietary uptake models

Tissue Monitoring Endpoints & Remedial Goals

Tissue Monitoring Endpoints

Tissue Monitoring Endpoints (TMEs) are target levels in diet biota tissue samples that will result in a hazard quotient (HQ) of 1 for the receptors of interest

The following TMEs were estimated:

- As & Se in larval mayfly based on the protection of the killdeer
- Se in adult mayfly based on the protection of the tree swallow

Inputs into the TME calculations are: receptor body weight, ingestion rates , toxicity reference values

Receptor	Metal	TME (mg/kg)
Killdeer	As	34 – 81
	Se	2.3 – 5.0
Tree Swallow	Se	63 – 148

Remedial Goals - Killdeer

Constituent	Sediment Concentration (Csed) [a] (mg/kg)	Refined Toxicity Reference Value (TRV) Range [b] NOAEL (mg/kg-BW-day)	Refined Toxicity Reference Value (TRV) Range [b] LOAEL (mg/kg-BW-day)	Calculated Diet Tissue Monitoring Endpoint (TME) [c] low (mg/kg)	Calculated Diet Tissue Monitoring Endpoint (TME) [c] high (mg/kg)
Inorganics					
Arsenic	41	5.8	13	34	81
Selenium	3	0.4	0.8	2.3	5.0

- **RG sediment agrees with toxicity derived RGs for arsenic (29-41 mg/kg) and selenium (2.8-3.2 mg/kg).**

[a] Maximum sediment remedial goals (RGs) based on effects to benthic invertebrates.

[b] TRVs are from the Baseline Ecological Risk Assessment (ARCADIS 2012).

[c] TME = [(THQ x TRV x BW) - (Cs x IRsed x SUF)] / (IRfd x SUF)
Assuming 100% of diet is invertebrates from source.
Receptor exposure parameters are from the Baseline Ecological Risk Assessment (ARCADIS 2012) and are presented below.

Exposure Assumptions			
Body Weight	BW	kg	0.095
Food Ingestion Rate	IRfd	kg/day	0.014
Soil/Sed Ingestion Rate	IRsed	kg/day	0.002
Site Use Factor	SUF	--	1
Target Hazard Quotient	THQ	--	1

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Remedial Goals - Tree Swallows

Constituent	Refined Toxicity Reference Value (TRV) Range [a] NOAEL (mg/kg-BW-day)	Refined Toxicity Reference Value (TRV) Range [a] LOAEL (mg/kg-BW-day)	Calculated Diet Tissue Monitoring Endpoint (TME) [b] low (mg/kg)	Calculated Diet Tissue Monitoring Endpoint (TME) [b] high (mg/kg)
Inorganics				
Selenium	0.4	0.7	1.6	2.8

- Arsenic was not determined to be a constituent of ecological concern (COEC).
- Selenium in sediment is below that of the site reference locations; therefore, the RG was set to equal 2x the reference sediment selenium concentration

Conclusions

- Target sediment concentrations for future long-term monitoring programs

Remedial Goal Options			
Receptor / Exposure Pathway	Reference Concentration	Threshold Range	Remedial Goal Range
Benthic Invertebrates			
Arsenic concentration in sediment	8	29 - 41	29 - 41
Selenium concentration in sediment	3	2.8 - 3.2	3.0 - 3.2

US Army Engineer Research and Development Center fate & transport model predict sediment mixing and deposition likely results in:

- Average **arsenic** concentrations within the RG range in all areas of the river system in less than 12 years
- Average **selenium** concentrations within the RG range in all areas of the river system in less than 26 years

Conclusions & Recommendations

- Arsenic & toxicity test correlations similar (Wang et al. 2013 ET&C)
  - Significant effects when concentrations > Arsenic PEC
- RGs: *Consensus-based* rather than *one* value for *one* organism
- No consensus values? (i.e. Se and Se species) – use site specific exposure-effects, multiple LOEs, and background concentration information




Acknowledgements

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